

Astrophysics of white dwarf binaries

Gijs Nelemans

Department of Astrophysics, IMAPP, Radboud University Nijmegen

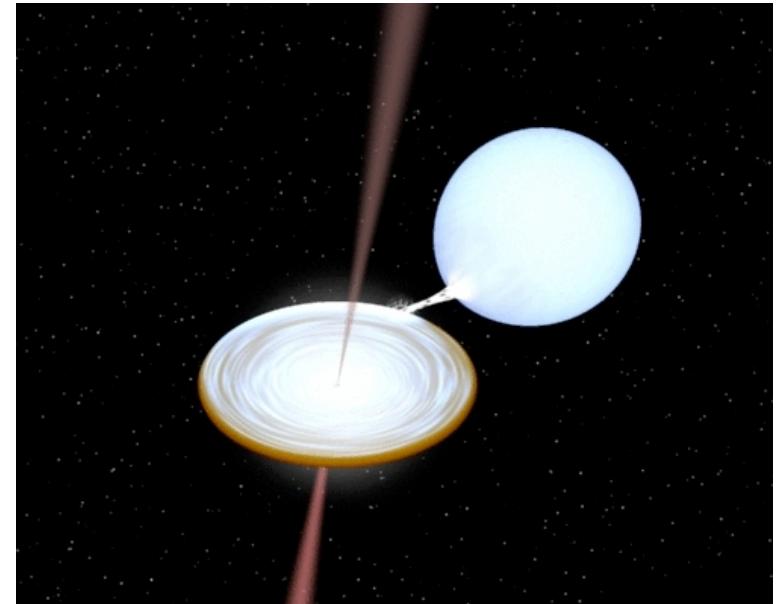


Outline

- Introduction: White dwarf binaries
- Astrophysics with double white dwarfs
 - Common-envelope evolution
 - Type Ia supernovae
 - Unique laboratories
- Relevance for/of LISA
- Current developments
 - Verification binaries (distances, AM CVn, short P systems)
 - Galactic white dwarf background
 - Complementary electro-magnetic observations
- Conclusions and outlook

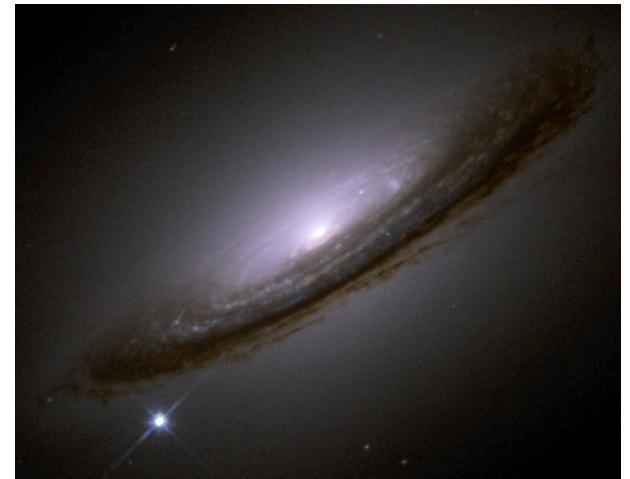
White dwarf binaries

- Most stars have low-mass, if $M < 8M_{\odot}$: white dwarf
- Most stars are binaries
- Detached white dwarf binaries:
 - Double white dwarfs
 - White dwarf-neutron stars
- Two types of *interacting* white dwarf binaries
 - With white dwarf accretors:
AM CVn systems (many)
 - With neutron star accretors:
Ultra-compact X-ray binaries (UCXBs)



Astrophysics with double white dwarfs

- White dwarf binary related Astrophysical questions
- Good tests for binary evolution
 - Most stars part of binary
 - Many spectacular phenomena (GRB, supernovae, micro-quasars)
 - Common-envelope evolution
- Type Ia supernovae
 - Used as standard candles to measure expansion universe
 - Exploding white dwarfs
- Unique laboratories
 - He accretors
 - Mass-transfer stability direct impact

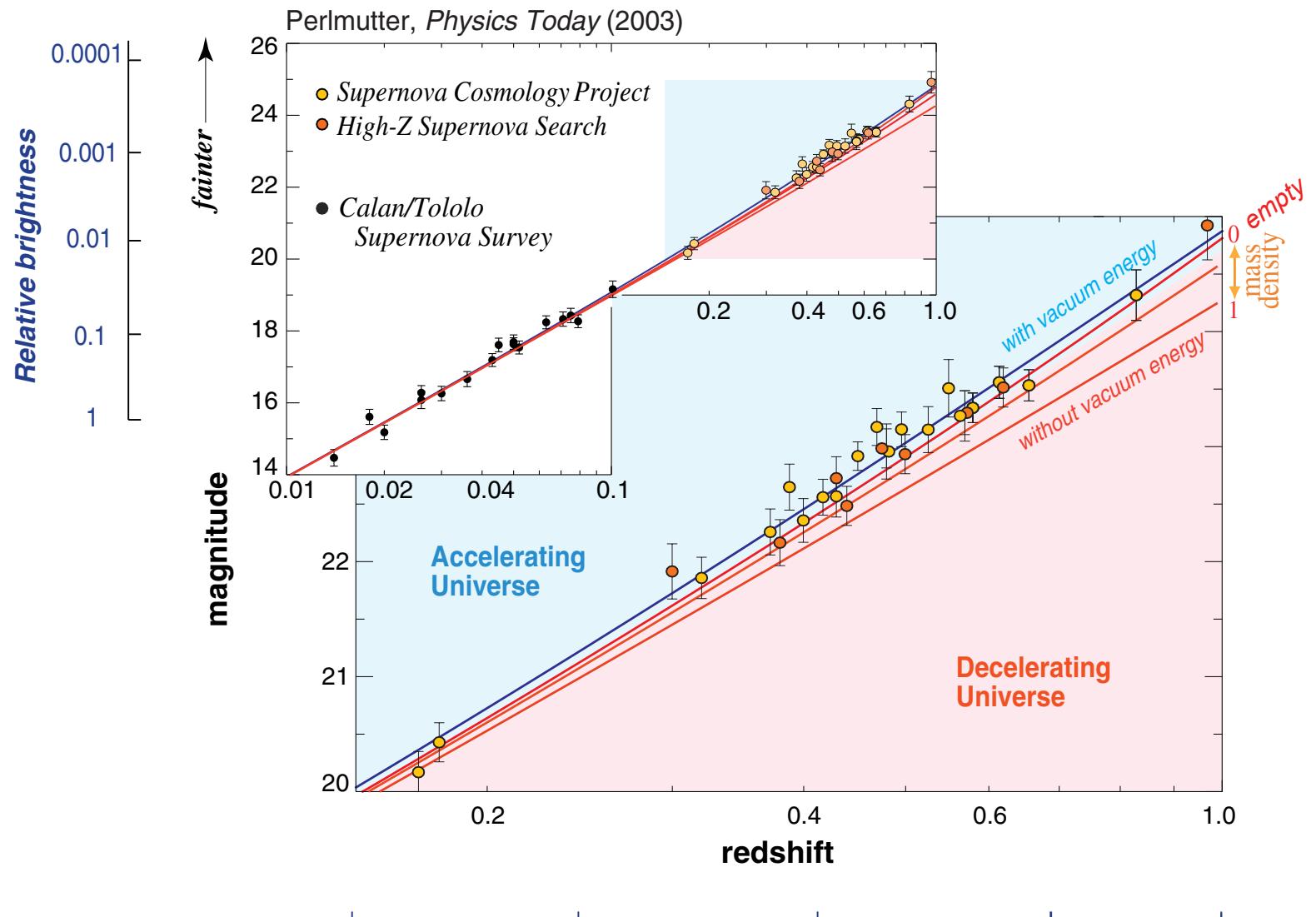


Common-envelope evolution

- White dwarf binaries excellent tests common-envelope:
- Spiral in of companion ***inside*** envelope giant
- “Standard” formalism: energy balance
- Standard common-envelope picture incorrect
 - Double white dwarfs used to reconstruct evolution
 - Not all common-envelopes lead to spiral-in
 - Not possible with energy balance
- Angular momentum balance is important
- Important for **all** compact binaries

Nelemans et al. 2000, Nelemans & Tout, 2005

Type Ia Supernovae



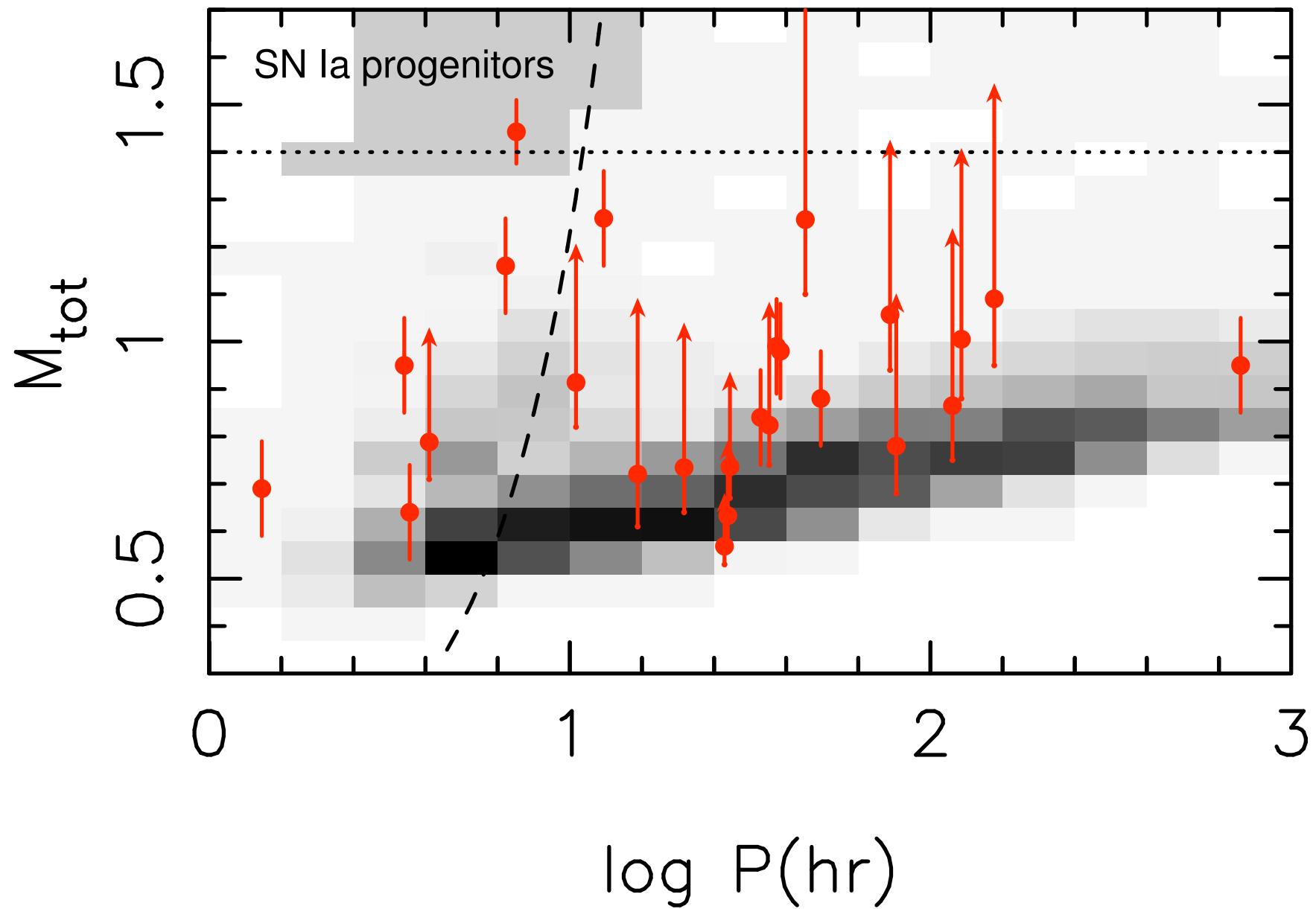
White dwarf mergers?

Scale of the Universe
[relative to today's scale]

Gjjs Nelemans

Radboud University Nijmegen



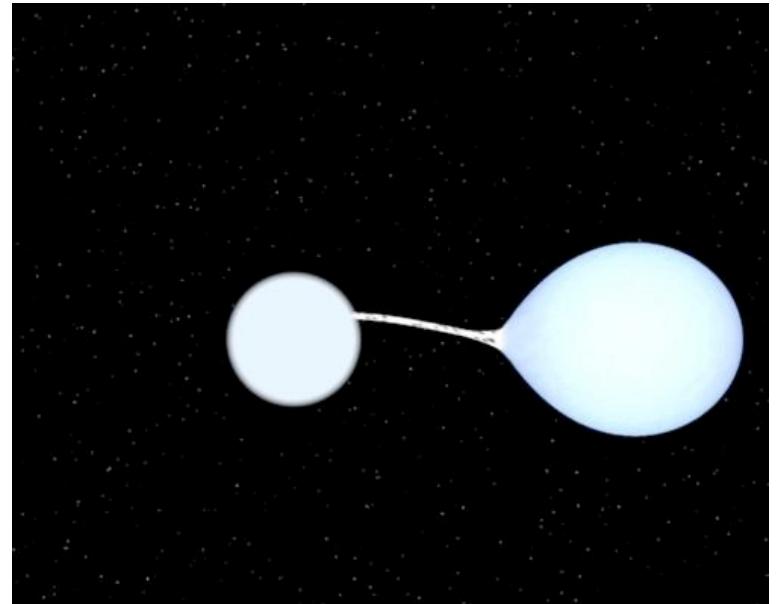


At least one candidate (consistent with predictions)

Unique laboratories

- Helium (or C/O) accretors
 - Helium (C/O) accretion disc
 - Window deep into stellar core
 - Signature of formation
- Mass transfer stability & tidal effects
- Direct impact accretion
 - Unique geometry
 - Can influence stability

(talk Motl)



Relevance for/of LISA

- Verification binaries
 - Some systems **will** be detected
 - Probe different parameters than electro-magnetic
- Galactic population of binaries
 - >10000 resolved binaries
 - Galactic background “noise”
 - Population studies
 - Galactic structure
- Recent developments:
 - Distances and masses verification binaries
 - Better understanding galactic background
 - Studies of complementary electro-magnetic observations
 - Surveys



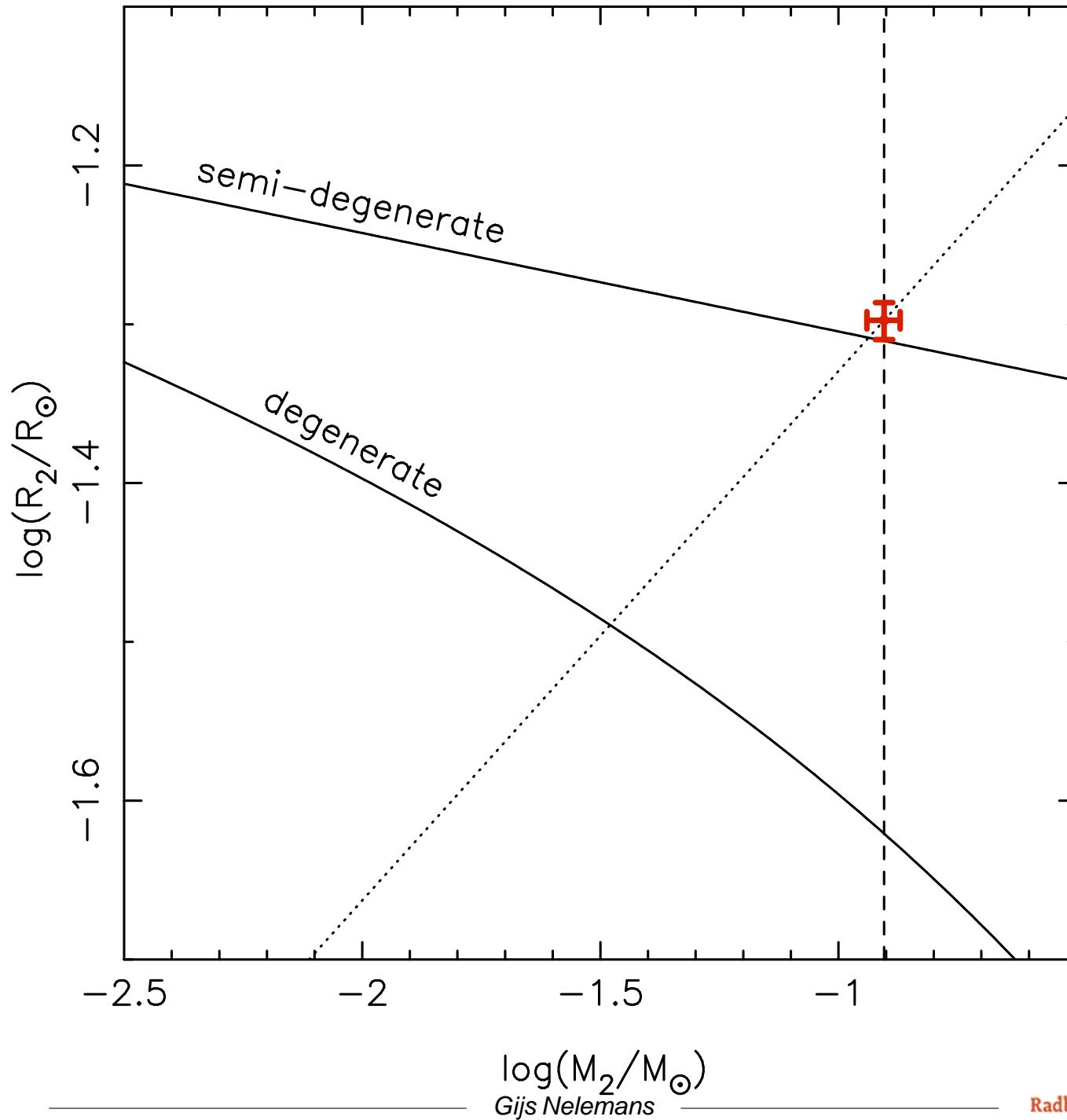
Relevance for/of LISA

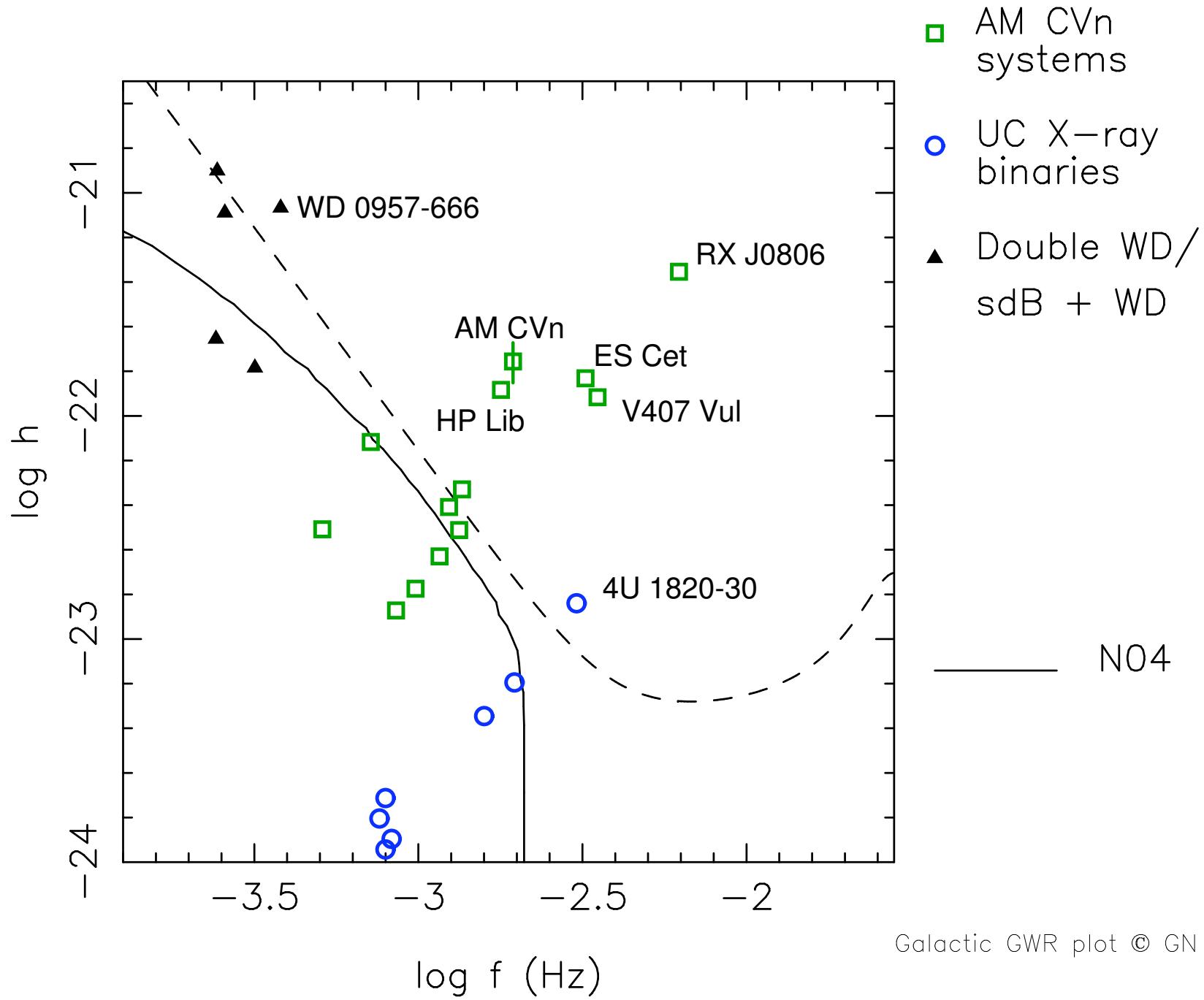
- Verification binaries
 - Some systems **will** be detected (**poster Wen**)
 - Probe different parameters than electro-magnetic
- Galactic population of binaries
 - >10000 resolved binaries
 - Galactic background “noise” (**poster Ruiter**)
 - Population studies (**poster Kumar**)
 - Galactic structure (**poster Holly-Bockelmann**)
- Recent developments:
 - Distances and masses verification binaries
 - Better understanding galactic background
 - Studies of complementary electro-magnetic observations
(**poster Branduardi-Raymond**)
 - Surveys

Verification binaries

- Number of known binaries should be detected
- Need to know parameters
- Distances
 - Are now 6 parallax distances
 - Two very close systems (< 100pc)
Thorstensen, 2003, priv. comm
 - Five from HST: e.g. $d_{AMCVn} = 606$ pc!
Roelofs et al. 2006, in prep
- Masses/mass ratios
 - Mass ratio often based on empirical relations for H discs
 - In AM CVn direct measurement of mass ratio: 0.18
 - With distance: tight constraint on masses
Roelofs et al. 2006, in press
 - Now **well calibrated** verification source!







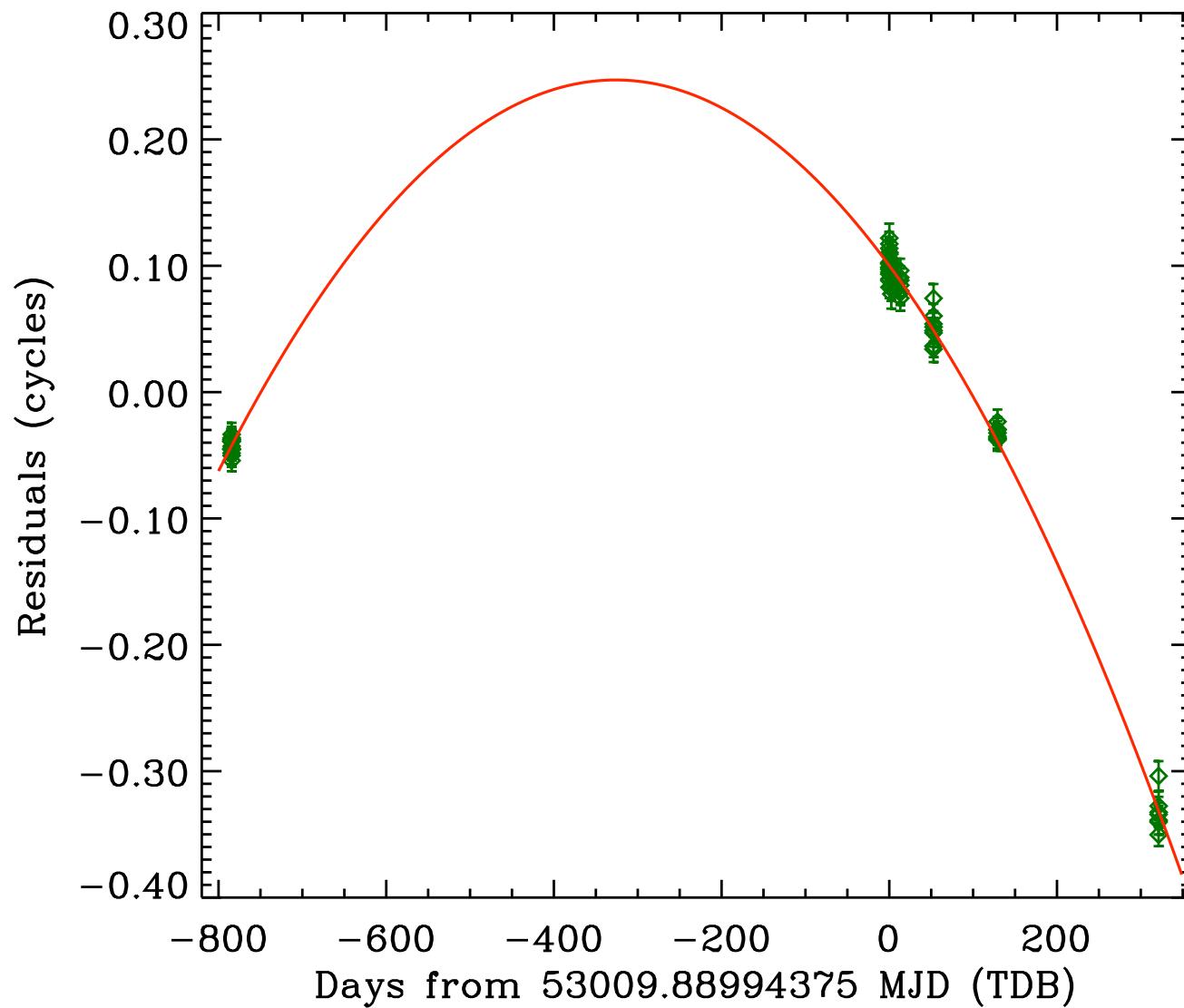
Galactic GWR plot © GN 2005

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Short period systems

- Two systems have extremely short periods
 - RX J0806.3+1527 ($P = 5.4$ min)
 - V407 Vul ($P=9.5$ min)
- Might be orbital \Rightarrow strong LISA sources
- But “problems”
 - Negative period derivatives
Israel et al., Strohmayer et al., Ramsay et al.
 - Low X-ray luminosities
 - Lifetimes
- Questions to be answered (soon)
 - Are period derivatives stable
 - Are periods orbital (spectra)





Strohmayer, 2005

Predicting Galactic binaries: population synthesis

- Simplified binary evolution

*Portegies Zwart & Verbunt, 1996, A&A, 309, 179,
Nelemans et al. 2001, A&A, 365, 491*

- Initial parameter distributions

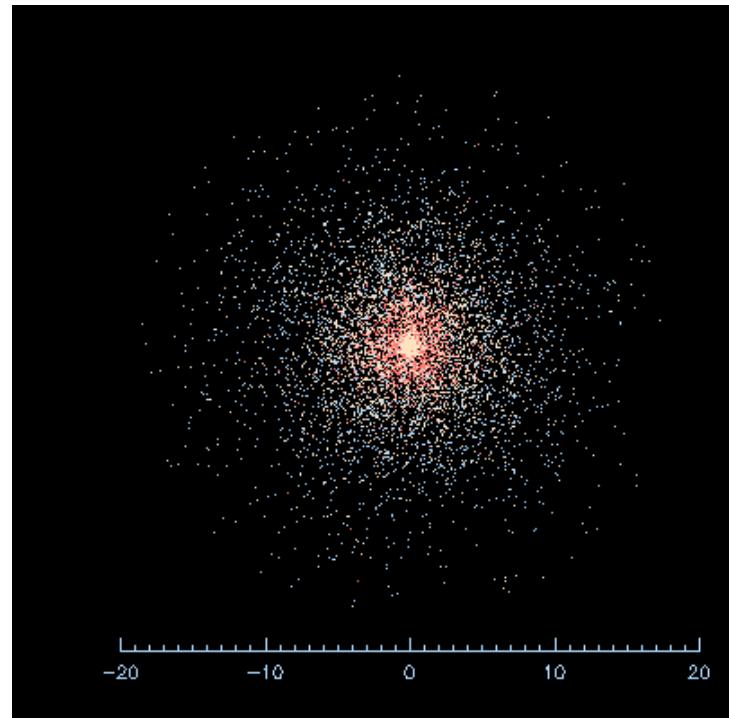
e.g. Kroupa, Tout & Gilmore, MNRAS, 262, 545

- Galactic model

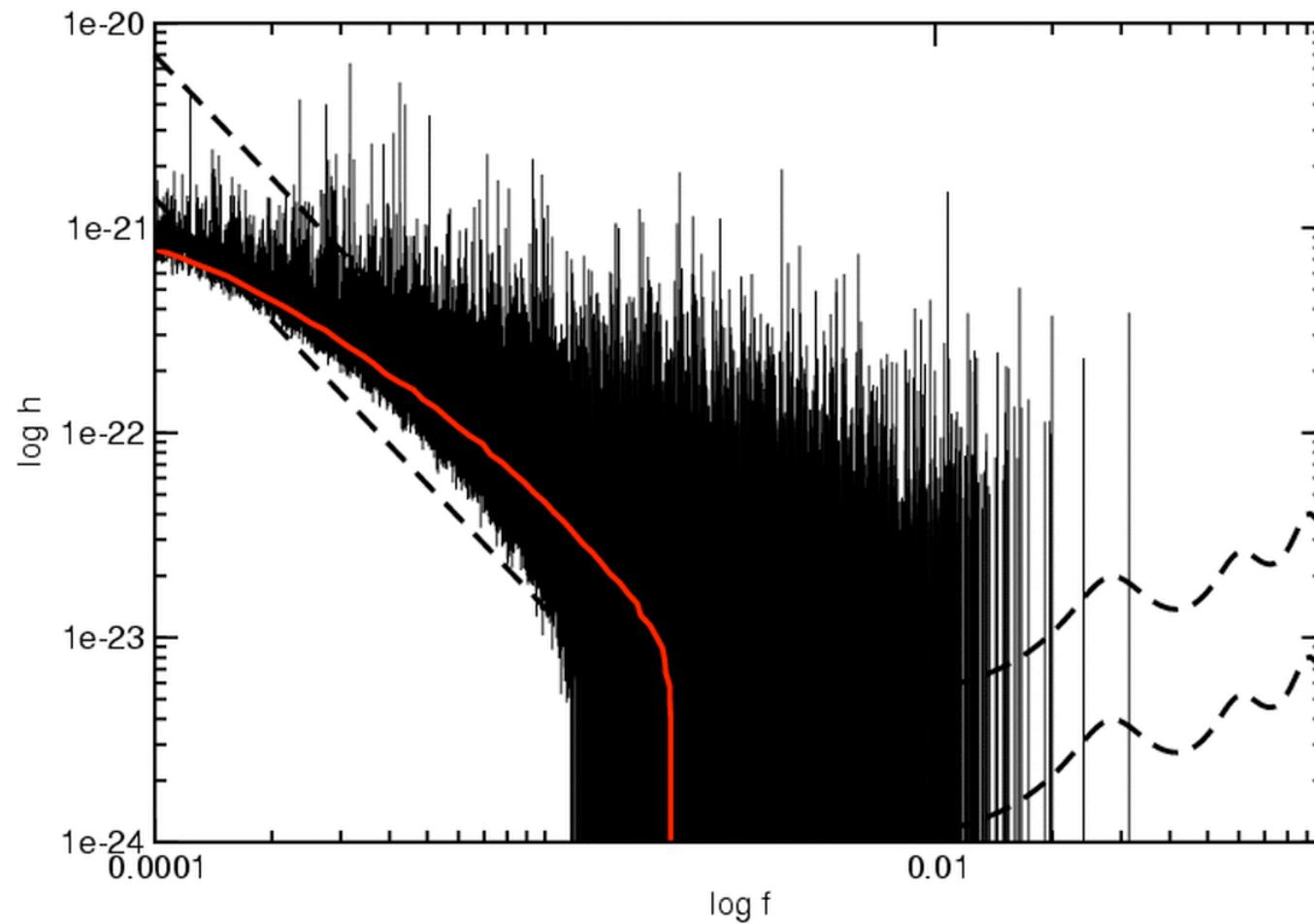
based on Boissier & Prantzos, 1999, MNRAS, 307, 857

- Disc component (axisymmetric)
- Bulge (spherical)
- Inside out star formation

- Uncertainties: need observations for testing



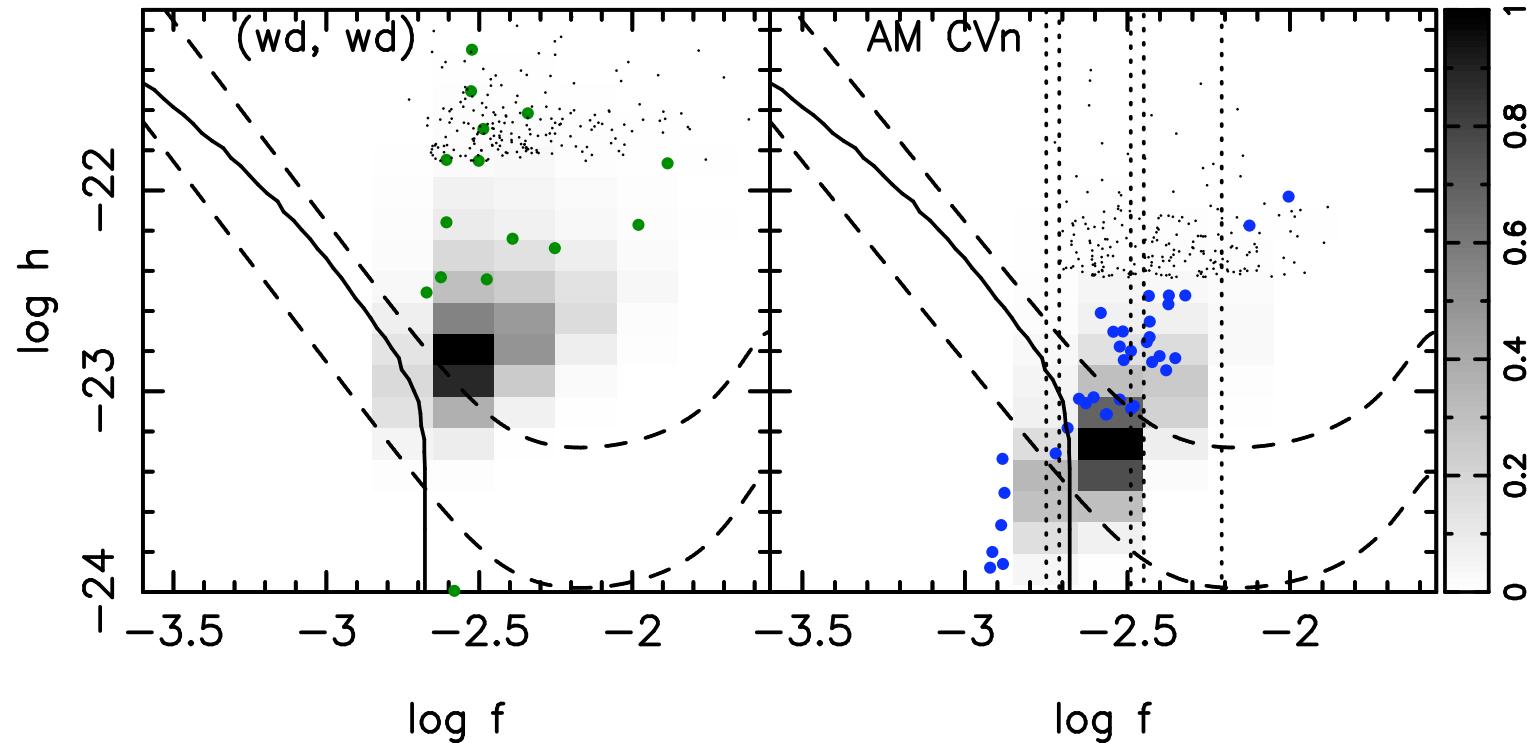
LISA signal of Galactic double white dwarfs



Nelemans, Yungelson, Portegies Zwart, MNRAS, 2004

Agreement with Hils, Bender & Webbink coincidence!
(also Neil's talk)

Expected resolved systems



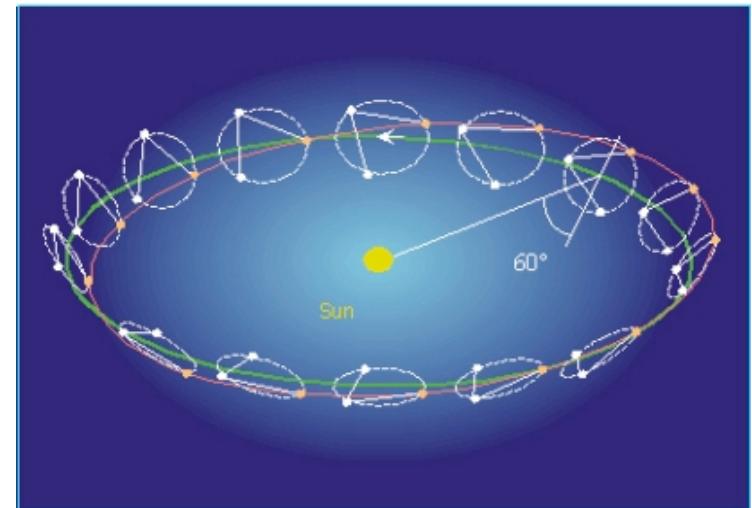
- resolved systems: ~ 11000 (wd, wd), ~ 10000 AM CVn, few tens neutron star binaries

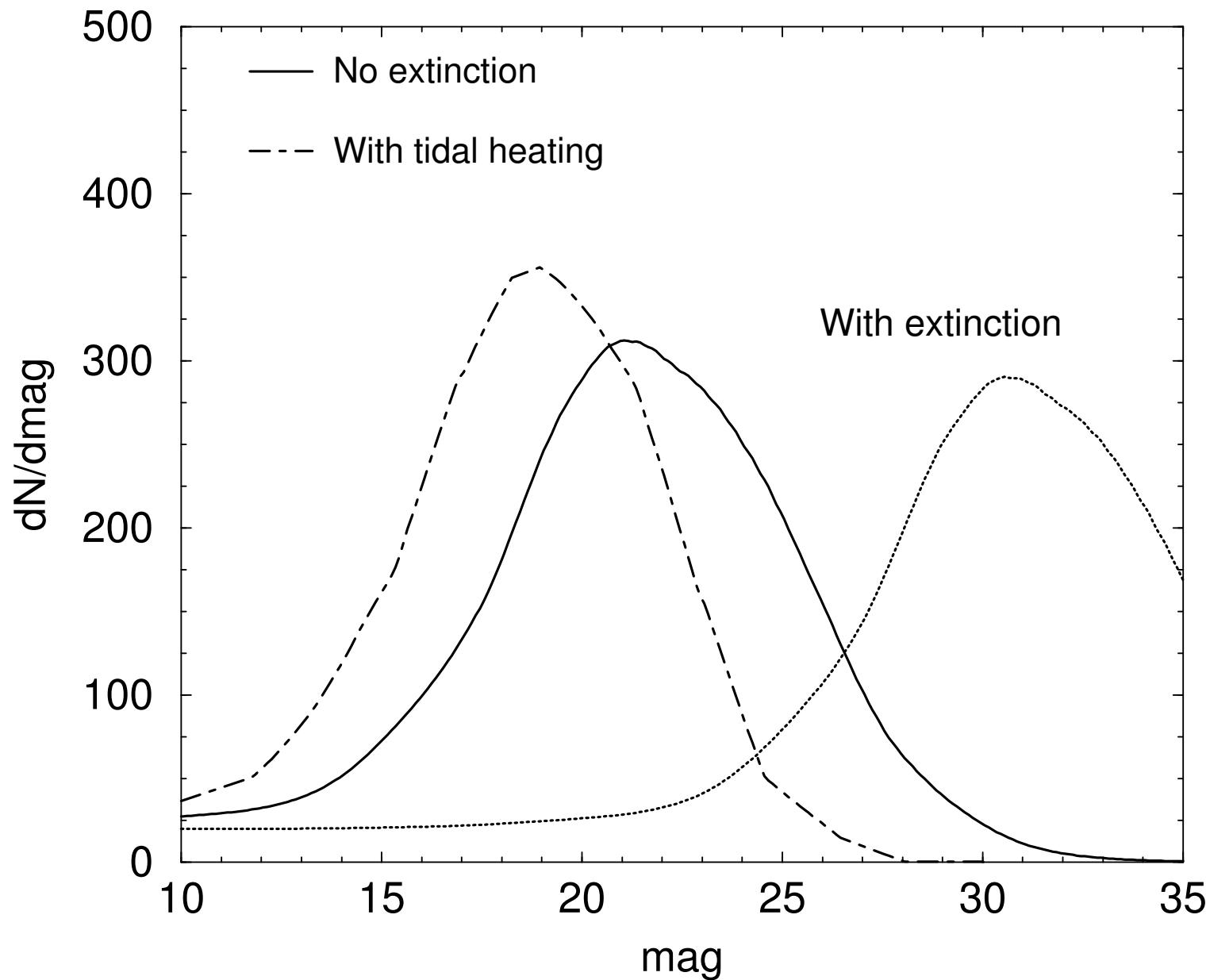
Nelemans, 2002, *Class. Quantum Grav.* 20S, 81, Nelemans, Yungelson & Portegies Zwart, *MNRAS*, 2004

(talk Chris Belczynski)

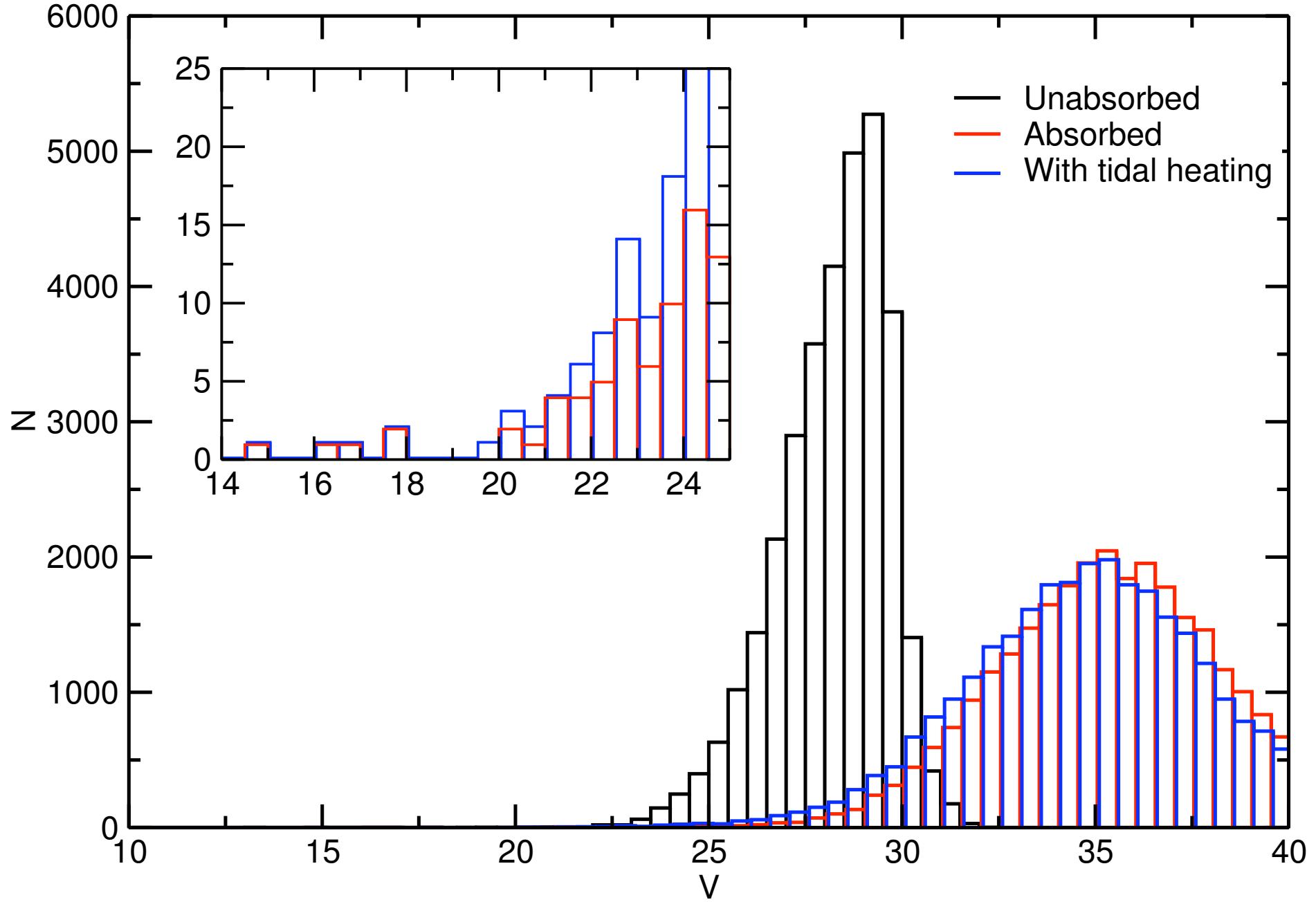
Complementary electro-magnetic observations

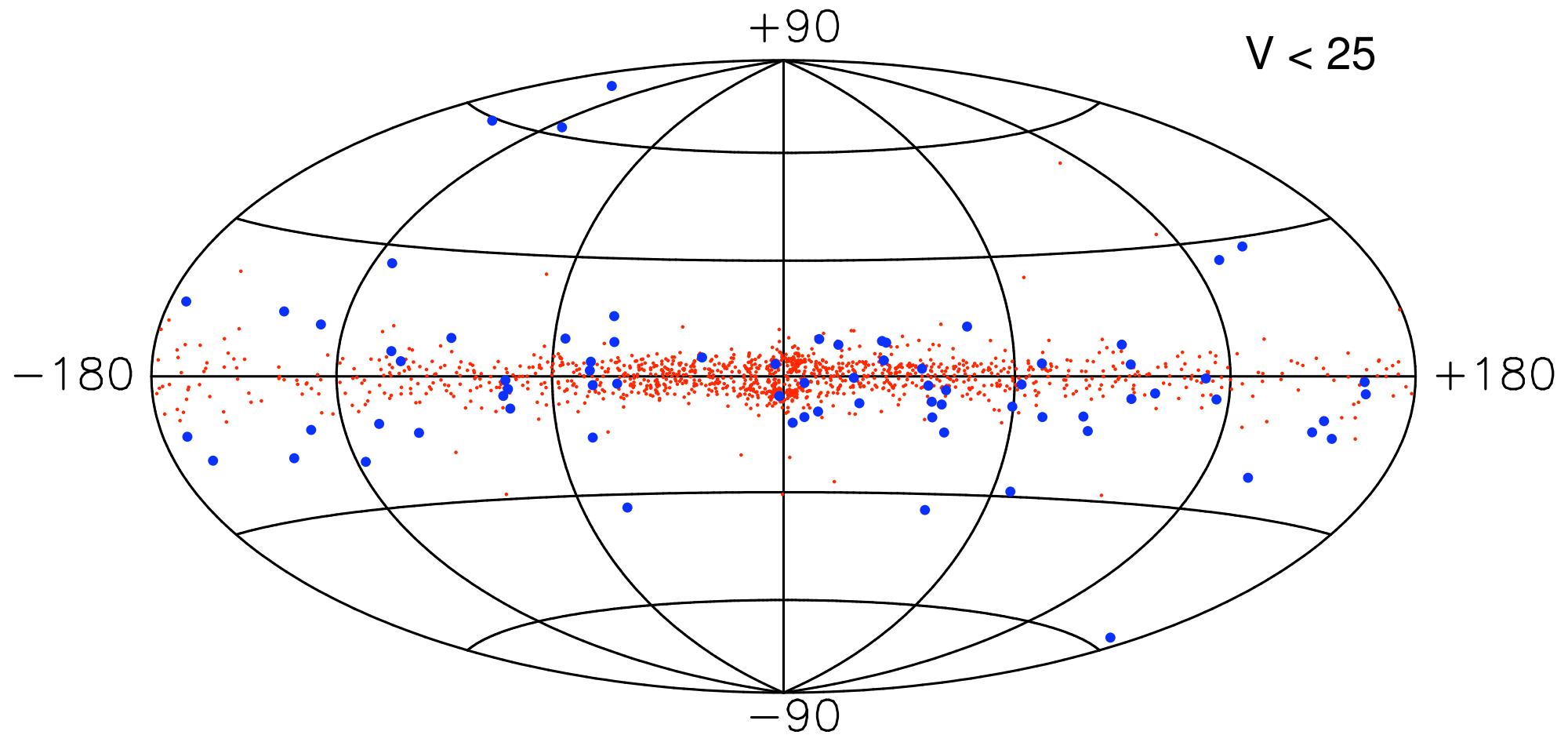
- Some positional information from LISA orbit
- GWR detectors:
simultaneous fitting of
8 parameters
(talks, posters)
- Complementary EM observations can fix some
(in particular position)
- Need large field of view (OmegaCam)
- Optical/IR, X-ray follow-up (X-Shooter, XEUS)
- Cooray et al. 2004: seem much too optimistic!



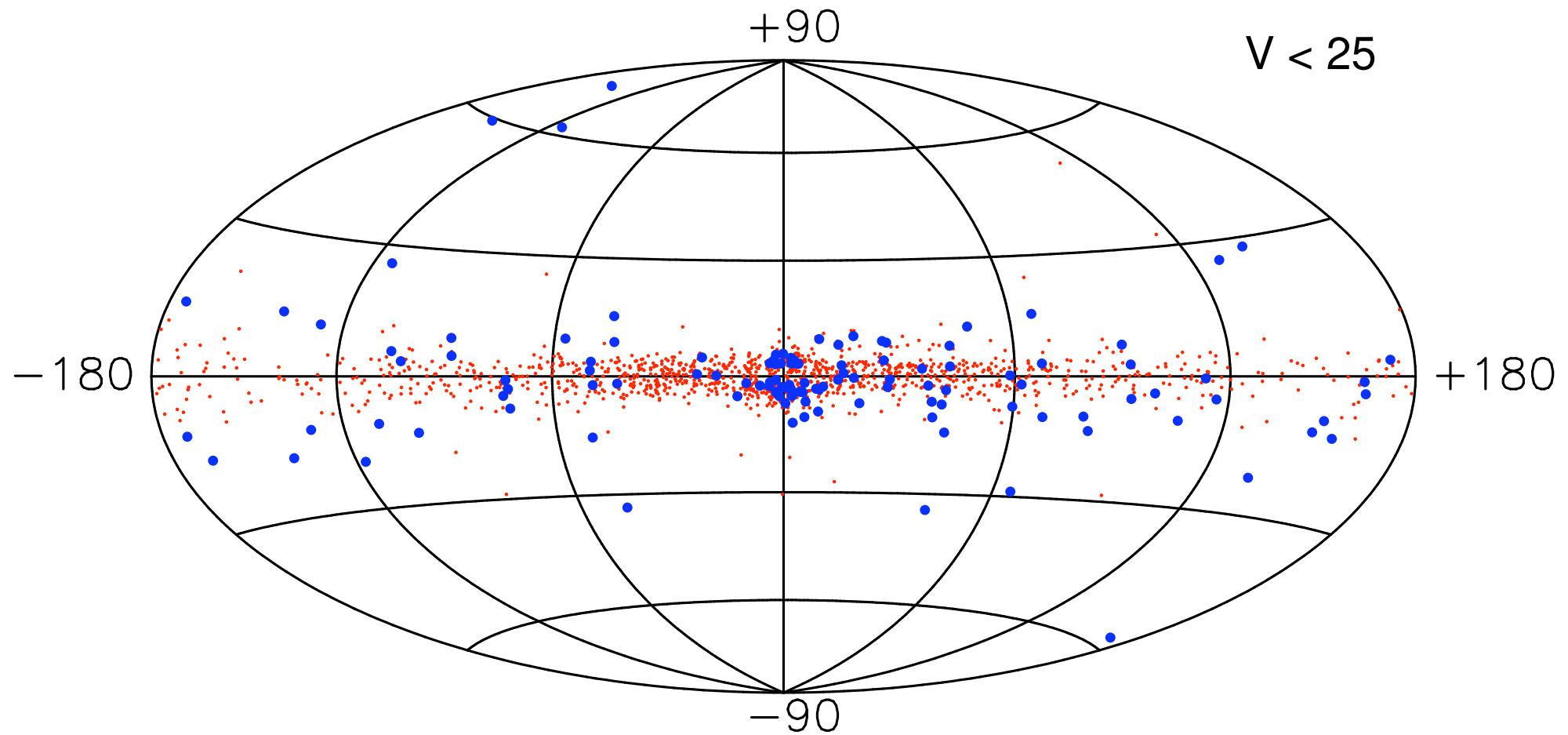


Cooray et al., 2004





Resolved + “strong” sources
1265 AM CVn systems, 75 double white dwarfs



With tidal heating

Iben et al. 1998

1265 AM CVn systems, 126 double white dwarfs



- **Large scale surveys**

- **EGAPS: European Galactic Plane Surveys**

PI Groot/Drew/Gänsicke

- Survey of full Galactic plane: large area
 - 5 filters u' , g' , r' , i' , $H\alpha$, later also with VISTA.
 - OmegaWhite *PI Groot*
 - * Homogeneous survey with OmegaCam on the VST
 - * Variability and emission lines
 - RATS (poster Branduardi-Raymond)
 - Proposed: **Chandra-Galactic Bulge Survey**

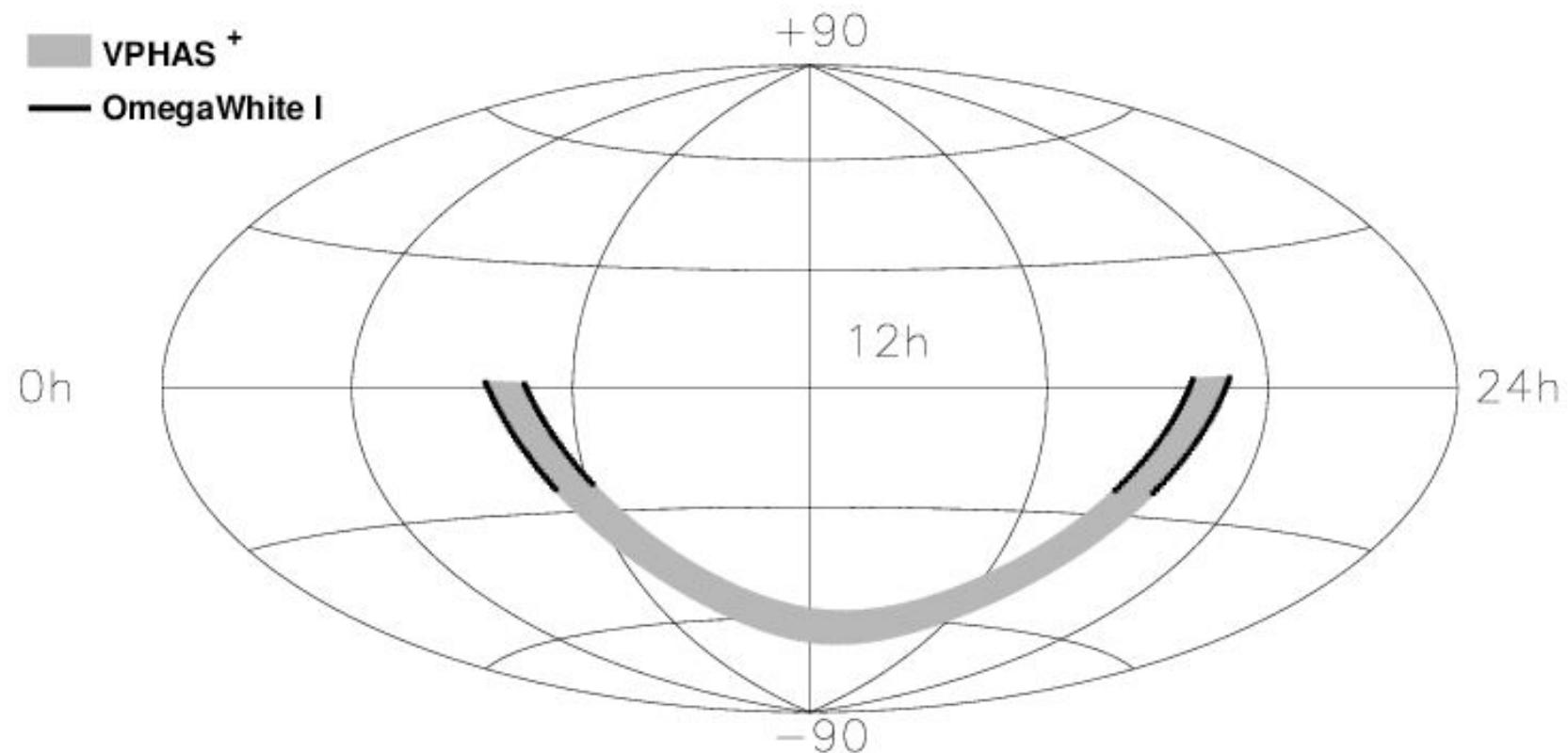
PI Jonker

- Probe densest (X-ray) population
 - Avoid too large extinction
 - Complementary optical survey (CTIO Blanco)
 - Not so near: **GAIA**

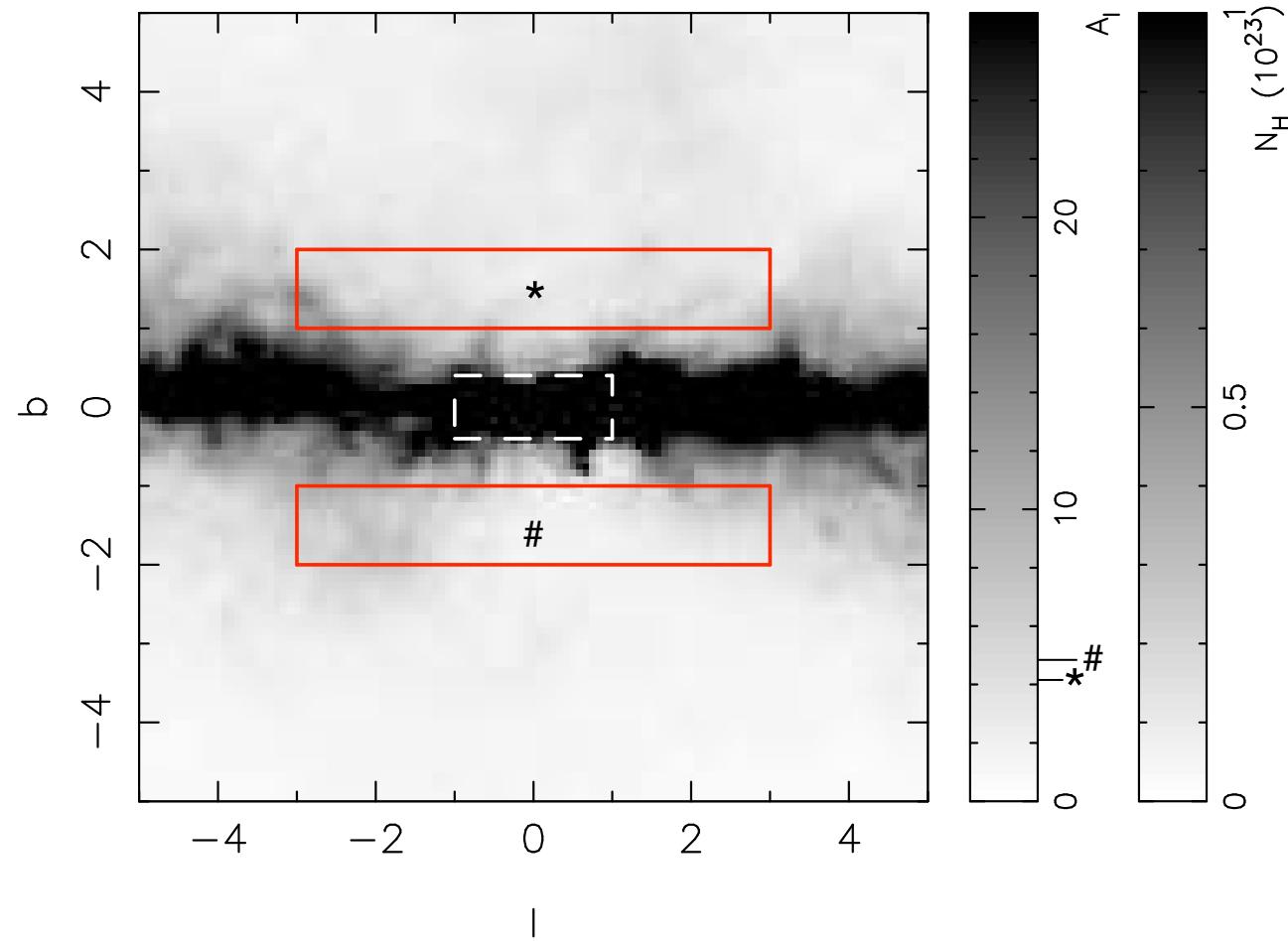
- Comprehensive modelling of (binary) stellar populations



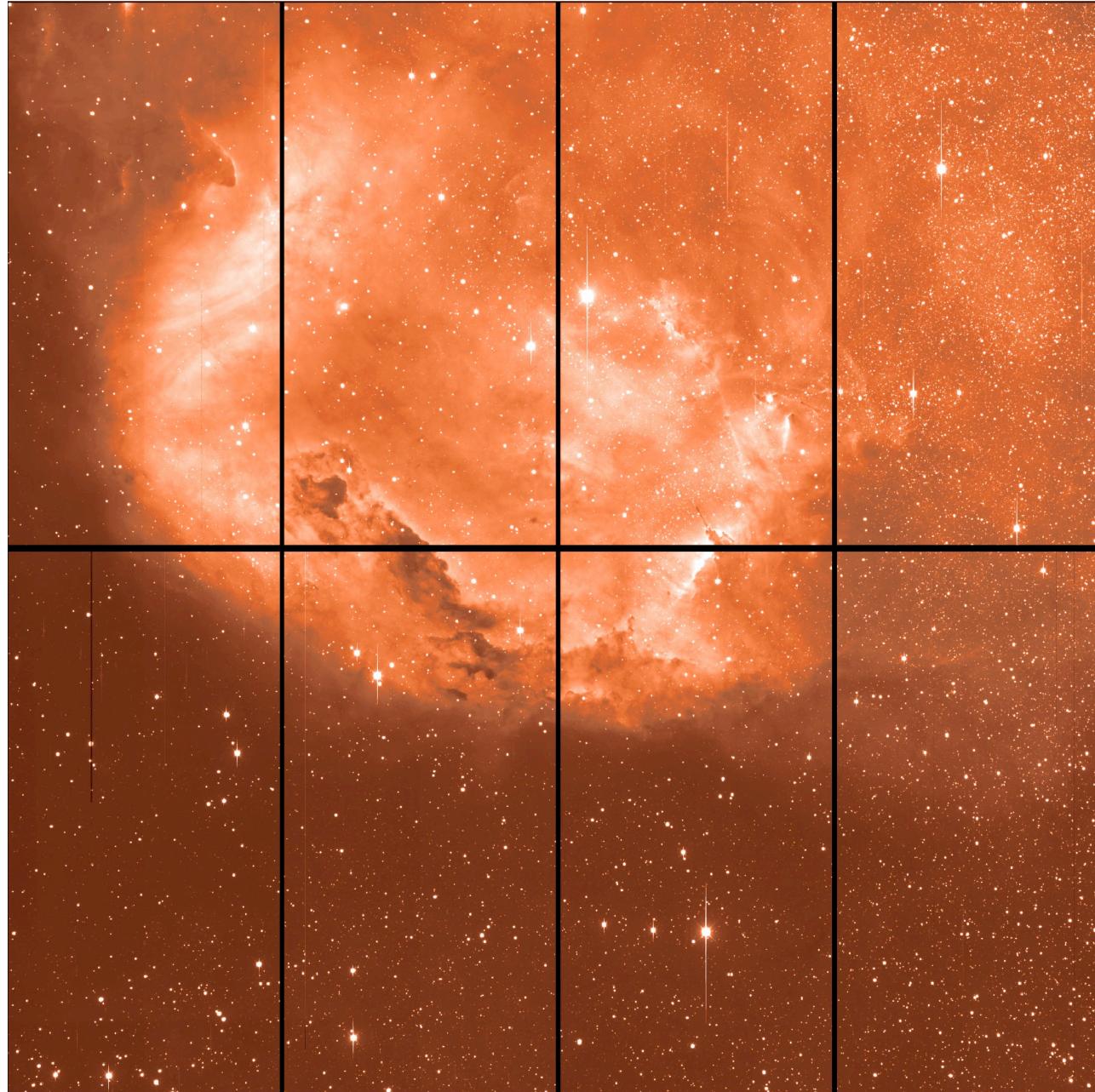
EGAPS (south)

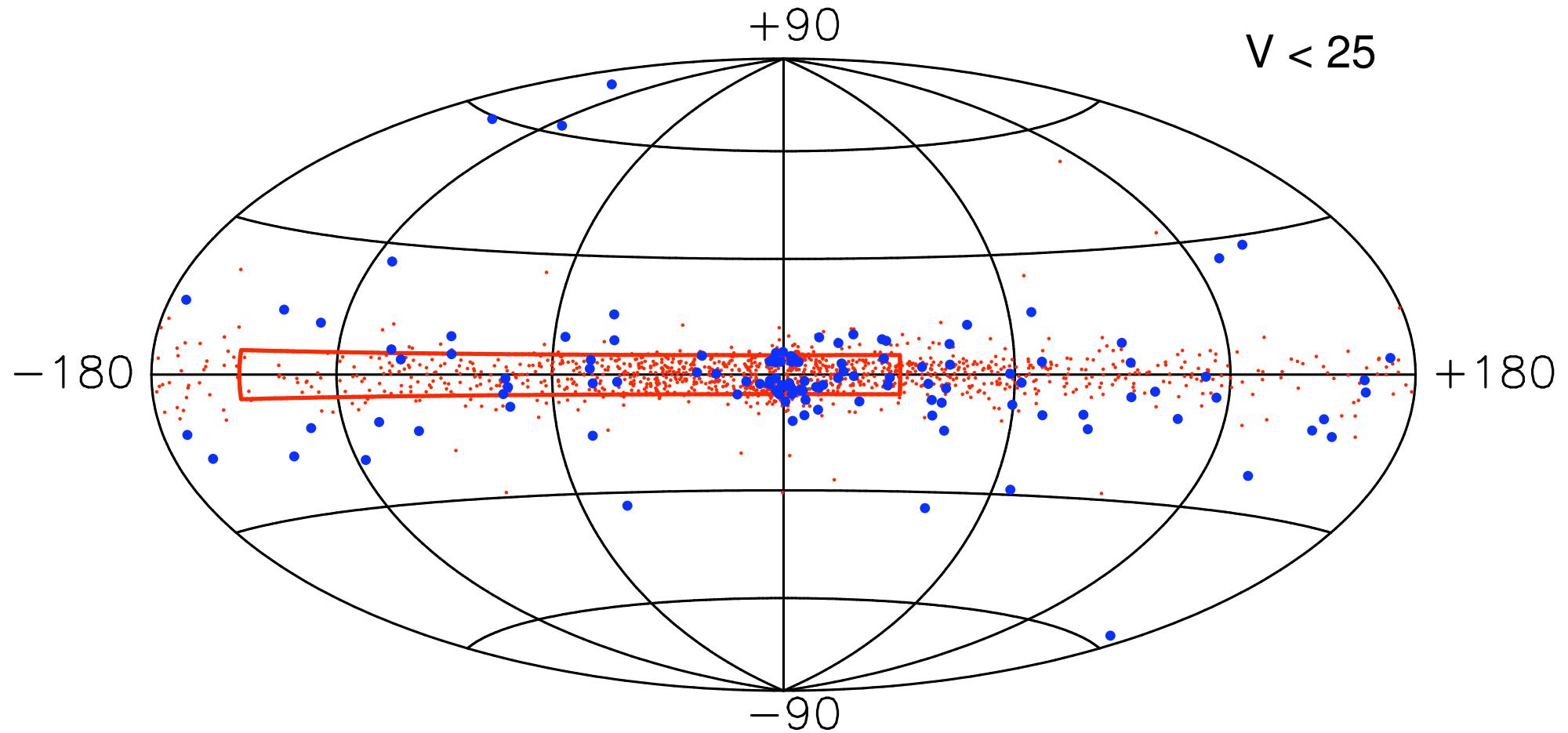


Chandra GBS



Chandra GBS





117 AM CVn systems, 13 double white dwarfs in OmegaWhite
762 AM CVn systems, 53 double white dwarfs in VPHAS⁺ area
(few AM CVns + UCXBs in Chandra GBS)

Outlook Astrophysics

- Background

- Overall population (number, average chirp mass): test binary evolution
 - Global positions Galaxy: test Galactic formation

- Resolved systems (thousands of systems)

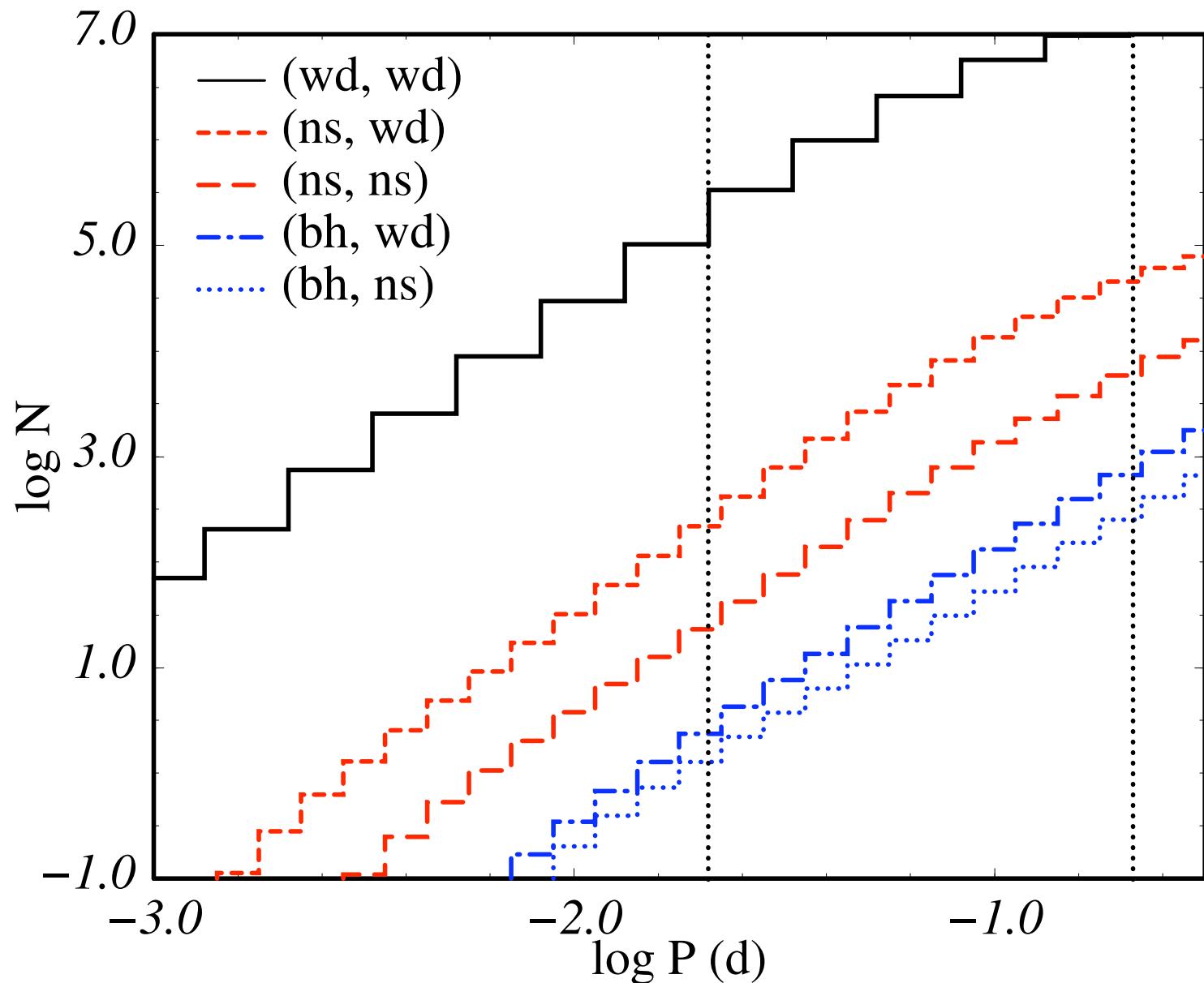
- Many (hundreds) with detailed parameters
 - Binary parameters: test binary evolution (SN Ia)
 - Inclinations: binary star formation in Galaxy
 - Evolving systems: test (tidal) interactions in binaries
 - Double white dwarfs vs AM CVns: test mass-transfer stability

- Strong sources (generally close to Earth)

- Scope for optical follow-up
 - Sky distribution different: first indication distance

Conclusions

- White dwarf binaries important for LISA
- Recent developments
 - Distances and parameters verification sources
 - Better constrained Galactic populations
 - Complementary EM observations
- Near future
 - Dedicated surveys (optical, X-ray)
 - Modelling EM emission
 - Comprehensive modelling Galaxy



Based on Nelemans, Yungelson & Portegies Zwart, 2001

SPY survey: finding close double white dwarfs

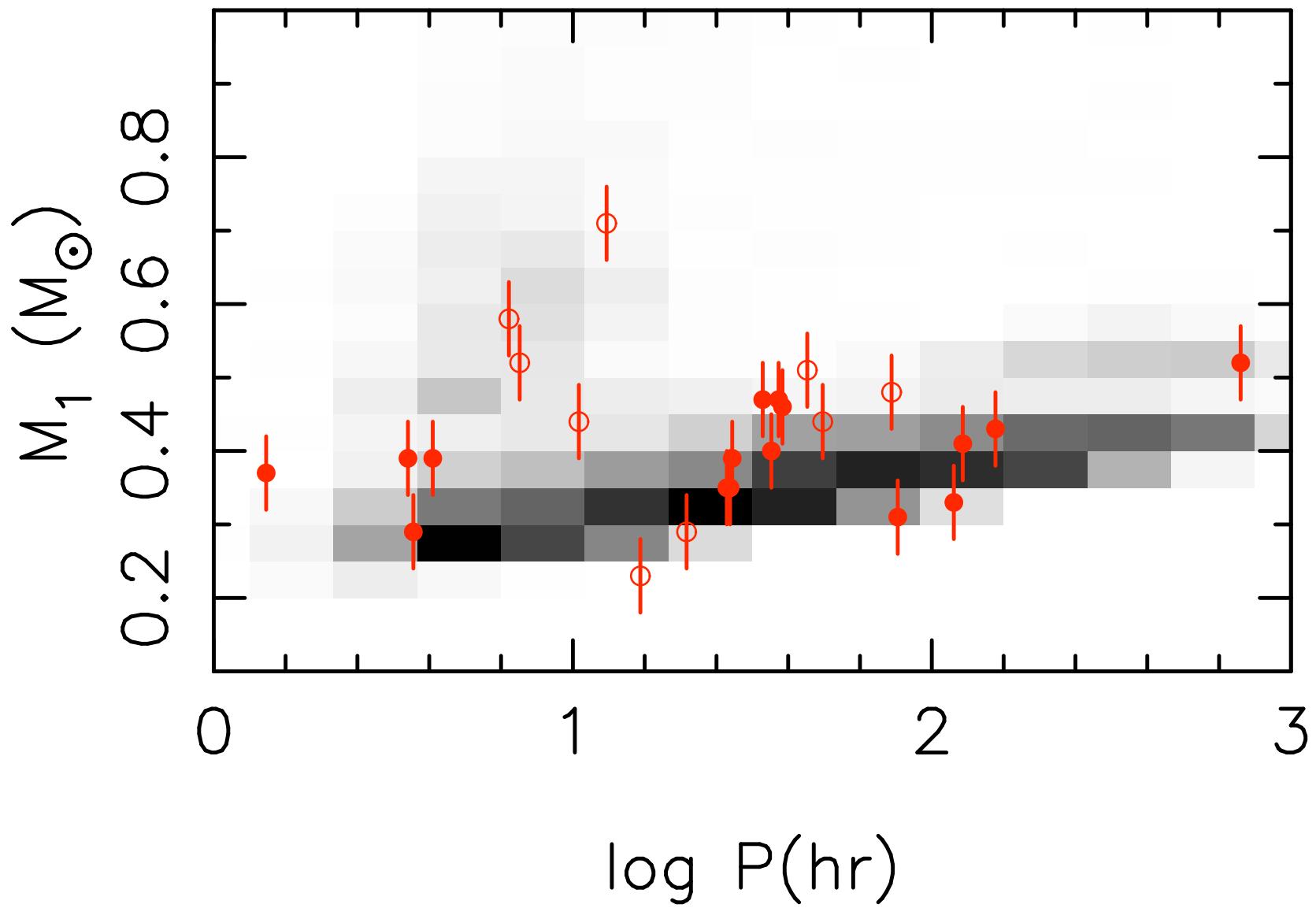
- ESO VLT survey
- ~ 1000 white dwarfs
- 2 spectra:
 Δ radial velocity
indicates binary

(*PI Napiwotzki*)

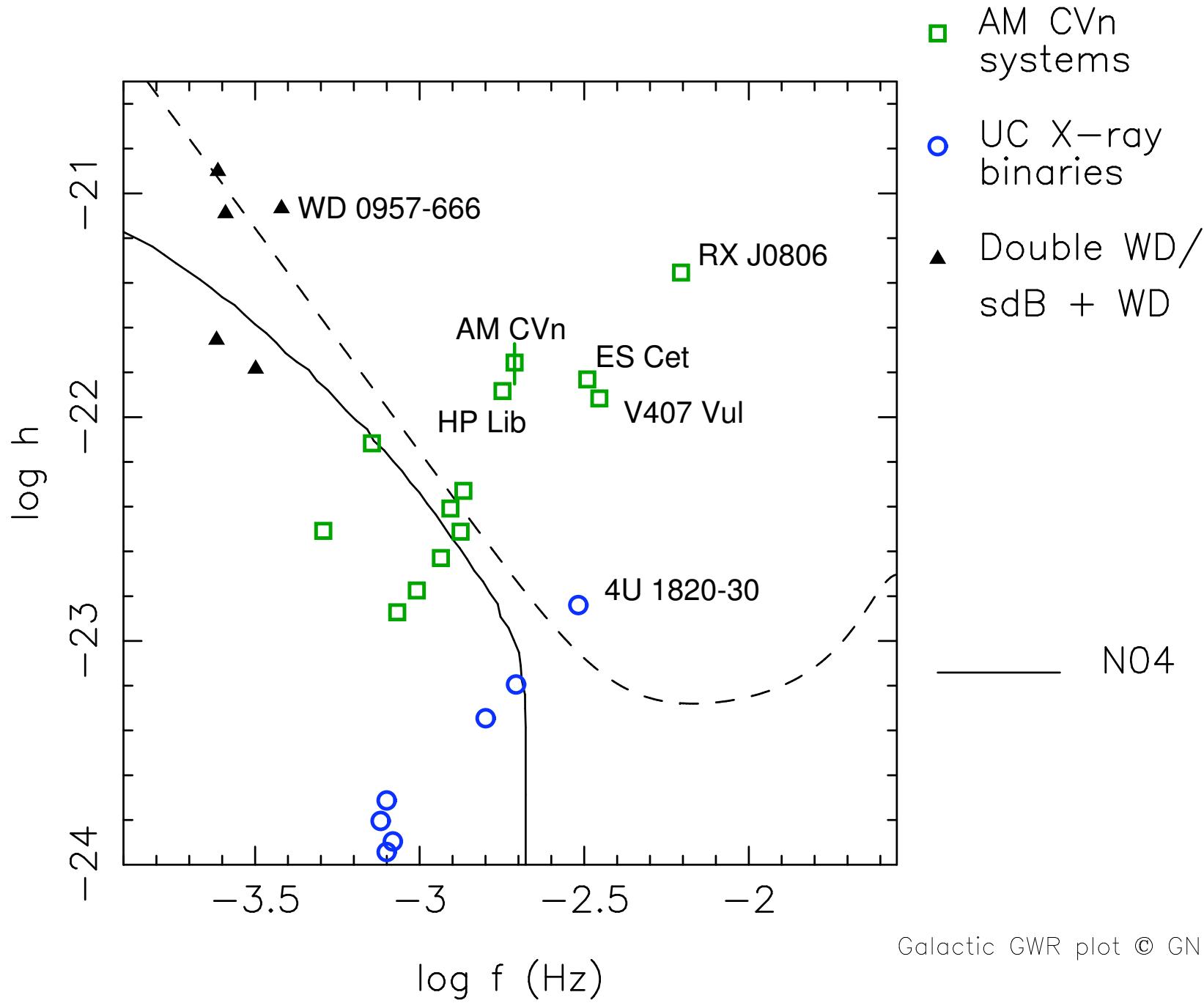


- Current status:
 - 178 with radial velocity variations (156 double white dwarfs)
 - More than ten times as many as were known!
 - Follow-up to determine system parameters (e.g. WHT, La Palma)
 - ~ 15 period determinations (between 0.3 and 5 d)

Napiwotzki et al., 2002,2004; Nelemans et al., 2005



Nelemans et al., 2005



Galactic GWR plot © GN 2005

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Measuring period derivatives

- Like pulsar timing, measure phase offset
- Thousands of \dot{f} measurement for double white dwarfs
- This gives chirp masses and distances

$$h = h(f, \mathcal{M}, d)$$

$$\dot{f} = \dot{f}(f, \mathcal{M})$$

- Maybe a few \ddot{f}
- \ddot{f} provides a direct check of GWR prediction

$$\dot{f} \propto f^{11/3} \Rightarrow \ddot{f} = \frac{11}{3} \frac{\dot{f}^2}{f}$$

- Need better understanding of LISA data analysis

Expected resolved systems

Type	birth rate (yr ⁻¹)	uncertainty factor	resolved systems
(wd, wd)	2.0×10^{-2}	5	11000
AM CVn	1.6×10^{-3}	50	10000
UCXB	1.1×10^{-5}	10	22
(ns, wd)	6.8×10^{-5}	50	8
(ns, ns)	5.2×10^{-5}	50	7

- Need better constrained models
- Therefore need more observations and surveys

